Faculty of Manufacturing Engineering

ULTRASONIC ASSISTED FUSED DEPOSITION MODELING FOR ACRYLONITRILE BUTADIENE STYRENE WASTE RECYCLING

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Master of Science in Manufacturing Engineering

2021

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A thesis submitted
in fulfilment of the requirements for the degree of Master of Science
in Manufacturing Engineering

Faculty of Manufacturing Engineering

UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2021

DECLARATION

I declare that this thesis entitled "Ultrasonic Assisted Fused Deposition Modeling for Acrylonitrile Butadiene Styrene Waste Recycling" is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.

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APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Master of Science in Manufacturing Engineering.

Signature	:	……………………………………..
Supervisor Name	:	……………………………………..
Date	:	……………………………………..

DEDICATION

Committed to my parents

Adore siblings

Respectable supervisors and lecturers

Loving colleagues and friends

ABSTRACT

Additive manufacturing (AM), also known as 3D printing, is a process that creates a physical object from a digital CAD data. Fused Deposition Modeling (FDM) is one of the common 3D printing processes. However, a large amount of waste produced due to printing and human errors. Waste has caused an impact on the environment due to the non-biodegradable polymer properties and this requires recycling of the waste polymers. However, recycled polymers deteriorate in terms of mechanical properties due to weak interlayer bonding. Hence, this study aims to investigate the effect of ultrasonic vibration on the improvement of mechanical properties of recycled Acrylonitrile Butadiene Styrene (ABS). ABS waste was granulated and extruded into a new filament that used to print the test specimen. A piezoelectric transducer mounted onto the FDM printer platform to transmit the vibration thoroughly during the printing of the test specimen. The ultrasonic frequency of the transducer controlled at 0 kHz, 10 kHz and 20 kHz. Specimen orientation controlled at the edge, flat and upright position (X, Y and Z). Tensile test and microstructure analysis carried out to determine the mechanical properties of the recycled ABS specimen at different ultrasonic frequencies and orientation. Analysis of variance (ANOVA) will determine the significant and optimum parameters. The result of the tensile test shows that there had an increment in Ultimate Tensile Strength in the range (UTS) of 11.03% to 67.61%; improvement of strain in the range of 1.30% to 45.83% and improvement of Modulus of Elasticity (MOE) in the range of 15.24% to 24.10%. Besides, the results from the microstructure analysis showed that size voids decreased from 230 µm to 30 µm when the ultrasonic frequency increased to 20 kHz. The results of ANOVA showed that ultrasonic frequency and orientation had a significant effect on the improvement of UTS, strain and MOE and the optimum parameter was 20 kHz of ultrasonic frequency and Y orientation. Hence, this study has shown that ultrasonic vibration can improve the mechanical properties of recycled ABS and reducing the number and size of voids and porosities in its microstructure.

PERMODELAN PEMENDAPAN LAKUR BERBANTU ULTRASONIK UNTUK MENGITAR SEMULA SISA AKRILONITRIL BUTADIENA STIRENA

ABSTRAK

Proses pembuatan tambahan (AM), juga dikenali sebagai percetakan 3D, ialah proses yang menbina fizikal objek dari data CAD digital. Permodelan pemendapan lakur (FDM) adalah salah satu proses percetakan yang lazim. Namun, sejumlah besar sisa dihasilkan kerana kesilapan percertakan dan pengguna. Ini telah menyebabkan kesan ke atas alam sekitar kerana sifat-sifat polimer tidak terbiodegradasi dan memerlukan proses kitar semula sisa polimer. Namun, polimer dikitar semula merosot dari segi sifat-sifat mekanikal. Oleh itu, tujuan kajian ini adalah untuk mengkaji kesan getaran ultrasonik pada peningkatan sifat-sifat mekanikal bahan sisa kitar semula akrilonitril butadiena stirena (ABS). Sisa ABS telah diproses untuk dijadikan filamen baru yang digunakan untuk mencetak spesimen ujian. Transduser piezoelektrik dipasang pada platform pencetak FDM untuk menghantar getaran dengan menyeluruh semasa percetakan spesimen ujian. Getaran ultrasonik transduser itu telah ditetapkan pada 0 kHz, 10 kHz dan 20 kHz. Specimen orientasi diletakkan pada kedudukan hujung, rata dan tegak (X, Y dan Z). Ujian tegangan dan analisis mikrostruktur telah dijalankan untuk menentukan sifat-sifat mekanik spesimen ABS kitar semula pada frekuensi ultrasonik yang berbeza dan orientasi. Analisis varians (ANOVA) telah menentukan parameter yang optimum. Hasil daripada ujian tegangan menunjukkan ada kenaikan dalam Kekuatan Tegangan Muktamad (UTS) dalam julat 11.03% kepada 67.61%; peningkatan Ketegangan dalam julat 1.30% kepada 45.83% dan peningkatan Modulus Keanjalan (MOE) dalam julat 15.24% kepada 24.10%. Di samping itu, keputusan analisis mikrostruktur menunjukkan bahawa saiz lompang telah menurun dari 230 µm ke 30 µm apabila getaran ultrasonik meningkat kepada 20 kHz. Keputusan ANOVA menunjukkan frekuensi ultrasonik dan orientasi mempunyai kesan yang besar pada peningkatan UTS, Ketegangan dan MOE dan parameter yang optimum ialah getaran ultrasonik 20 kHz dan orientasi Y. Kajian ini telah menunjukkan getaran ultrasonik boleh meningkatkan sifat-sifat mekanikal bahan ABS kitar semula selain mengurangkan bilangan dan saiz keporosan dan lompang mikrostrukturnya.

ACKNOWLEDGEMENTS

I wish to show my deepest appreciation to my supervisor, Associate Professor Dr. Shajahan Bin Maidin from the Faculty of Manufacturing Engineering, Universiti Teknikal Malaysia Melaka (UTeM). Supervisor kept guiding and supporting and motivating me for completing this research. I also wish to extend my thanks to my co-supervisor, Associate Professor Ir. Dr. Rizal Bin Alkahari, for his guidance and supports. The assistance provided by technicians, lecturer and colleagues were greatly appreciated. Besides, I would like to thank my friends and family who always encourage and support me to finish this research. I am eternally grateful that UTeM is giving me this learning platform and providing Zamalah scholarship for financial support in my research.

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LIST OF ABBREVIATIONS

3D	-	3 Dimensional
ABS	-	Acrylonitrile Butadiene Styrene
AM	-	Additive manufacturing
ANOVA	-	Analysis of variance
ASTM	-	American Society for Testing and Materials
BJ	-	Binder jetting
CAD	-	Computer-aided design
CAE	-	Computer-aided engineering
CAM	-	Computer-aided manufacturing
CNC	-	Computer numerical control
DED	-	Direct energy deposition
DMLS	-	Direct metal laser sintering
DOD	-	Drop on demand
DOE	-	Design of experiment
DOF	-	Degree of freedom
EBM	-	Electron beam melting
FDM	-	Fused deposition modeling
LOM	-	Laminated sheet manufacturing
ME	-	Material extrusion
MJ	-	Material jetting
MOE	-	Modulus of elasticity
PBF	-	Powder bed fusion
PC	-	Polycarbonate
PLA	-	Polylactic Acid
SEM	-	Scanning electron microscope
SHS	-	Selective heat sintering

SL	-	Sheet lamination
SLA	-	Stereolithography
SLM	-	Selective laser melting
SLS	-	Selective laser sintering
STL	-	Stereolithography
UAM	-	Ultrasonic additive manufacturing
UTM	-	Universal testing machine
UTS	-	Ultimate tensile strength

LIST OF PUBLICATIONS

Journal

Maidin, Shajahan and Abdullah, Zulkeflee and Hieng, Ting and Alkahari, Rizal, 2020. Ultrasonic assisted Fused Deposition Modeling to Improve Mechanical Properties of Recycled Acrylonitrile Butadiene Styrene. *International Journal of Mechanical and Mechatronics Engineering*, 20(2), pp. 45-53.

Book Chapter

Maidin, Shajahan and Abdullah, Zulkeflee and Hieng, Ting., 2020. Investigation of Recycled Acrylonitrile Butadiene Styrene for Additive Manufacturing. *Implementation and Evaluation of Green Materials in Technology Development: Emerging Research and Opportunities*, pp. 130-154. doi:10.4018/978-1-7998-1374-3.ch007 10.4018/978-1-7998-1374-3.ch007.

Maidin, Shajahan and Chong, See and Heing, Ting and Abdullah, Zulkeflee and Alkahari, Rizal, 2019. Stab Resistant Analysis of Body Armour Design Features Manufactured via Fused Deposition Modelling Process. *Textile Manufacturing Processes*, pp. 1-13. doi: 10.5772/intechopen.86439.

CHAPTER 1

INTRODUCTION

1.1 Background

The American Society for Testing and Materials (ASTM) defines Additive Manufacturing (AM) as a process that creates a 3-dimensional (3D) object by joining material from 3D computer-aided design (CAD) data, usually layer upon layer which is opposed to the subtractive manufacturing process (ASTM International, 2013). The layers of material are layered down successively until a 3D object is created (Al-maliki, 2015). AM process can create a physical part by depositing raw material which is in solid or liquid form according to the CAD data without creating any waste and without using any tools. Previously, AM is used in industries or research to create a prototype, but now AM technology can be used to produce a functional end-user part.

AM technology can be divided into two phases, which are virtual and physical. For the virtual phase. For the virtual phase, 3D CAD data can be prepared by using any CAD software. After that, a physical model can be created by following the CAD data to deposit the material onto the printing platform. Material extrusion is one of the AM technology. For this research, Fused Deposition Modeling (FDM) will be focused on investigating the mechanical properties and microstructure of the part to be 3D printed. Open source FDM is usually a lower cost if compared to other AM technology and it is the most common AM technology (Bourell et al., 2017). The material in filament form will be heated and fed through the heated nozzle for deposition onto the printing platform. When the 3D shape object is cooled, the desired shape of the 3D object forms. Besides, the amorphous